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PERFORMANCE OF STEEL STUD WALLS SUBJECTED TO BLAST LOADS

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14. ABSTRACT

Past research has demonstrated that steel stud walls can perform well when subjected to large blast events. The construction methods needed to achieve good performance that take advantage of the inherent ductility offered by steel, however, have been costly and have often required the use of specialized connection details that allow a stud to reach its full flexural and/or tensile capacities prior to connection failure. The goal of the current study is to develop techniques for mitigating large blast loads acting against steel stud walls using conventional construction materials and techniques. Two issues of concern for the current research are: 1) the performance under blast loads of typical connections, either commercial clips or the standard screwed-stud-to-track, has yet to be fully examined, and 2) current methods of design do not incorporate the mechanical interaction of veneer layers for potentially increasing the blast resistance of steel stud walls. To better understand the role played by connection design details and wall system construction details, research for this project includes laboratory testing, field testing, and computational modeling. In this paper, the authors provide an overview of the research program and a summary of the findings that have been developed to date. From the data collected during this project, designs that exhibit a balance of simplistic, economic, and adequate protection will be developed.

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Performance of Steel Stud Walls Subjected to Blast Loads

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ABSTRACT

Past research has demonstrated that steel stud walls can perform well when subjected to large blast events. The construction methods needed to achieve good performance that take advantage of the inherent ductility offered by steel, however, have been costly and have often required the use of specialized connection details that allow a stud to reach its full flexural and/or tensile capacities prior to connection failure. The goal of the current study is to develop techniques for mitigating large blast loads acting against steel stud walls using conventional construction materials and techniques. Two issues of concern for the current research are: 1) the performance under blast loads of typical connections, either commercial clips or the standard screwed-stud-to-track, has yet to be fully examined, and 2) current methods of design do not incorporate the mechanical interaction of veneer layers for potentially increasing the blast resistance of steel stud walls. To better understand the role played by connection design details and wall system construction details, research for this project includes laboratory testing, field testing, and computational modeling. In this paper, the authors provide an overview of the research program and a summary of the findings that have been developed to date. From the data collected during this project, designs that exhibit a balance of simplistic, economic, and adequate protection will be developed.

INTRODUCTION

Construction trends have brought about an increase in the use of cold-formed steel studs in Air Force facilities. Furthermore, previous research by the Department of State (DOS) and the Engineer Research and Development Center (ERDC) of the U.S. Army Corps of Engineers (DiPaolo and Woodson, 2006) and by the Air Force Research Laboratory (AFRL) (Salim, Dinan, and Townsend, 2005 and Salim, Muller, and Dinan, 2005) have shown that steel stud walls have significant potential for mitigating large blast events. The current state of steel stud research, however, has not addressed all the variables that can influence the behavior of typical wall systems. These previous steel stud research programs were aimed at protection of facilities designed to withstand threats that are more demanding than the typical Unified

Facility Criteria 4-010-01 (UFC, 2007) threats that standard DOD and government facilities are designed to withstand. As a result, there is a research gap that exists in the blast-resistant design of conventional steel stud wall systems. Figure 1 illustrates a typical resistance function for steel stud wall behavior (Salim, Muller, and Dinan, 2005). In order to withstand high demand blast threats, previous efforts have focused on designing the connections to get the full tensile membrane behavior of wall system components. For standard military and government structures, this level of response is far beyond the required capacity and is quite costly. Thus, two areas of research can be identified as still having potential for changing the behavior of these wall systems: 1) the lack of data on connections, either commercial clips or the standard screwed-stud-to-track, and their influence on the allowable response under a blast load have yet to be fully examined; 2) current methods of design do not incorporate the mechanical interaction of veneer layers for potentially increasing the resistance of a steel stud wall.

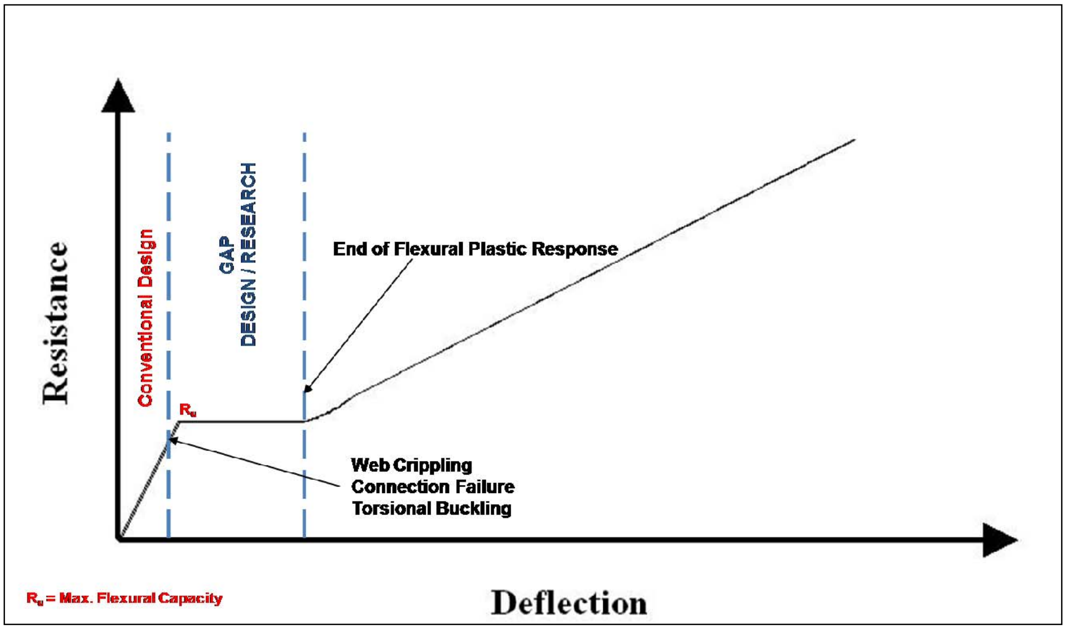


Figure 1: Typical Steel Stud Resistance Function and Research Gap

The first area of research recognizes the development of commercial connectors, intended for hurricane, seismic or large load reversal applications, as having potential in retrofit or new construction applications for blast mitigation. These technologies could form the bridge between the standard screwed-stud-to-track method and the findings of previous work by DOS, ERDC, and AFRL. The previous work led to connection designs for fully developing the axial capacity of steel studs prior to connection failure, but they were large and expensive. Aside from commercial connectors, the issue of ductility limits for traditional connectors has also been recognized by the ASCE Committee on Cold-Formed Steel as a topic that, to date, has not been fully researched.

The second area of research is based on observations from a recent experiment performed by AFRL at Tyndall AFB. A forensic and analytical post-test analysis led

to the hypothesis that the non-structural veneer of a steel stud wall system had acted compositely, increasing the overall stiffness of the system (Grumbach, Naito, and Dinan, 2007). In the past, such veneers as stucco or brick have been ignored in calculating the resistance of a wall system, only utilizing their potential as added mass for dynamic analysis and not for providing any strength.

OBJECTIVES

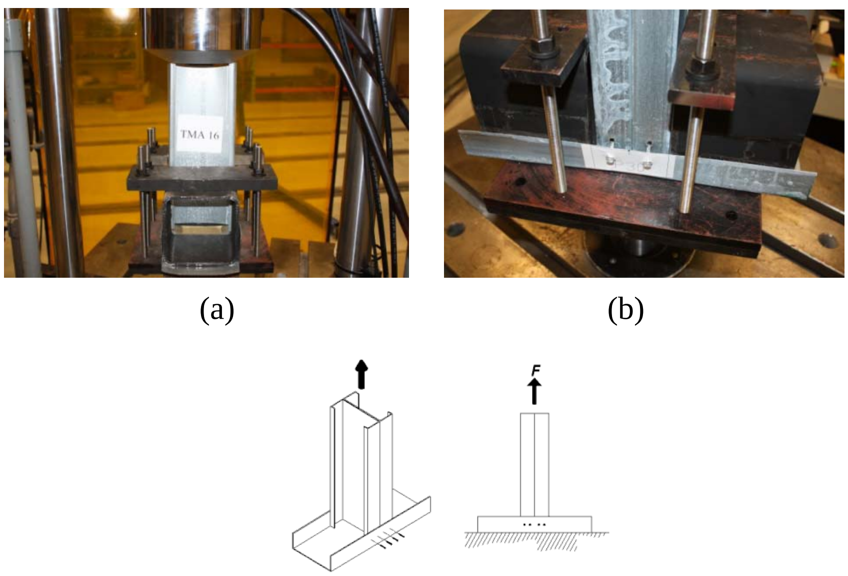
Building from previous research, a main objective of the current study is to create an analytical methodology—validated against test data—that can accurately predict response limit states of various types of steel stud wall assemblies. Another objective is the development of a standard that will allow engineers to have the option of adding the increased resistance of veneers that can perform compositely with cold-formed steel studs. To meet these objectives, the current research project includes detailed finite element analyses and a series of laboratory tests that are intended to measure fundamental aspects of steel stud behavior including connection response. Primary factors in the selection of steel stud wall systems for use in Air Force facilities will be performance under blast loads, system cost, ease of construction, and availability of materials.

CHARACTERIZATION OF STEEL STUD PERFORMANCE

To characterize the response of steel stud walls for use in Air Force facilities, it is important to recognize the wide range of construction practices that exist. Steel stud walls can be used as load-bearing components or non-load-bearing components, and a variety of exterior finishes and internal sheathing may be used. From an economic perspective, it is desirable to select wall configurations that are commonly used along with materials that are readily available. While it is possible to develop significant blast resistance with steel stud walls, tests to date have shown that specially designed fasteners that attach the studs to the structural floor and floor/roof beams are needed to develop this capacity (Dinan, 2005 and Shull, 2002). The use of these special fasteners is costly and requires experienced workers for correct installation. Thus, currently available methods for developing adequate blast resistance are expensive. To meet the objectives of the current project, it is desirable to utilize wall construction techniques that use readily available materials so that costs are kept to a minimum. Accordingly, the test program aims to characterize how standard cold-formed steel stud walls, using common sheathing materials such as drywall, oriented strand board (OSB), stucco, etc., utilizing conventional structural connections (e.g., slip track) and potentially proprietary connection devices, perform under blast loads.

Experimental Test Program. Laboratory experiments have been proposed to assist in the objectives of characterizing the capacity and response behavior of cold-form steel studs. Three component-level experiments have been devised before full-scale static experiments will be performed. The component level experiments are comprised of the following: 1) Tensile Membrane Action (TMA); 2) Bending and Prying Action (BPA) and 3) Crippling and Crushing Action (CCA).

The first series of component experiments, TMA, is for exploring the axial-tensile capacity of the steel-stud-to-track connection. Figure 2 shows the experimental setup. Steel studs are placed back-to-back, for symmetry, and then attached by various screw configurations to the track. As described previously, connection designs have been developed for achieving the full capacity of the steel stud; however, the aim of the TMA experiments is to explore the spectrum between full capacity and the single conventional screw installation (Figure 2(b)). Using this setup, seventy-three samples have been tested in an MTS load frame under quasi-static loading—0.5 inches per minute—to record each scenario's load versus deflection response. The specimens have included combinations of various track and stud thicknesses with different screw diameters and quantities. At the lower end of the spectrum was a 20-gauge track and stud screwed together by a single #8 self-tapping framing screw per flange/stud intersection. On the higher end of the spectrum, a 12-gauge track and stud were similarly placed together with six #12 self-tapping screws per flange/stud intersection. An additional nine samples were examined at an increasing loading rate up to 2.0 inches per minute.



(a) (b)

(c)

Figure 2: TMA Experimental Setup

The second series of component tests is the BPA experiments. This series examines the identical test matrix as the TMA series but subjects the samples to rotation and shear through a cantilever loading condition (Figure 3). The objective is to investigate rotational capacity of the stud in the track. The track is assumed to be held rigidly to the support with the focus of the testing to determine the degree of rotation at which the track and stud disconnect. Similarly to the TMA series, seventy-three samples have been tested in an MTS load frame under displacement control at a loading rate of 0.5 inch per minute. An additional nine samples were examined at varying rates up to 2.0 inches per minute.

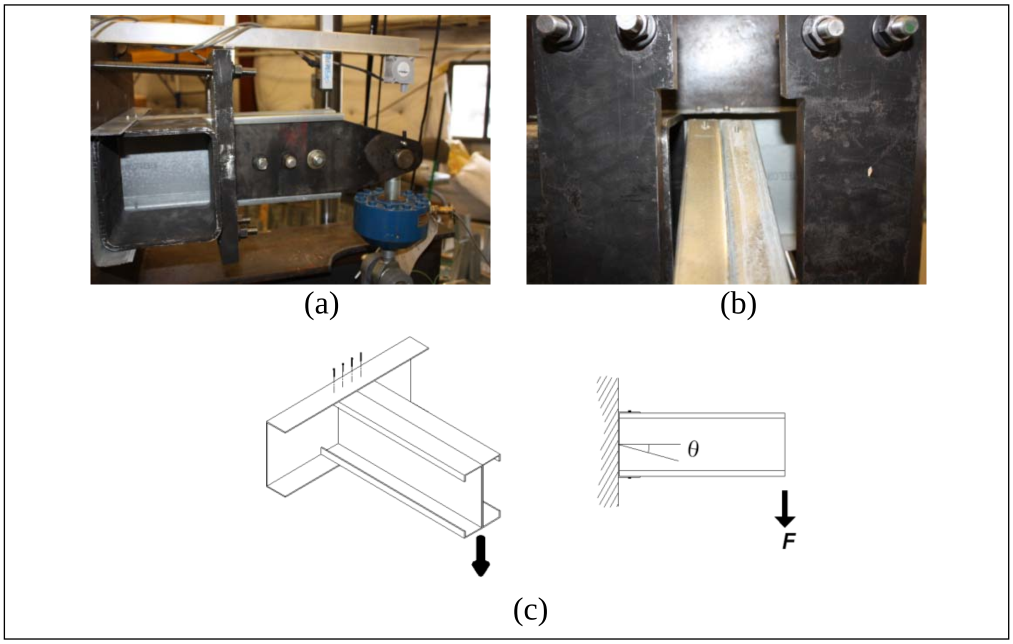


Figure 3: BPA Experimental Setup

The third and final component series exploring cold-form steel capacity is the CCA experiments. The purpose of this test series is to evaluate the shear or crippling capacity of the studs inside of the track channel. It is hypothesized that studs with deep webs and/or thin gauge sections have additional absorption capabilities not mathematically accounted for in current blast design procedures. Current procedures focus only on the flexural absorption of the steel stud and use the shear or connection capacity as a limit state (SBEDS 2008). At the time of this writing, the BPA series was still in progress. Figure 4 shows the generalized schematic of the test setup; the experiment utilizes an MTS load frame under displacement control and is patterned similarly to a four-point bending experiment.

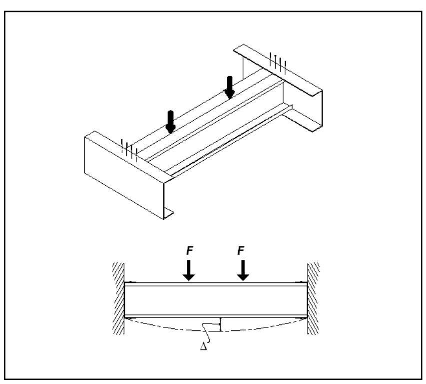
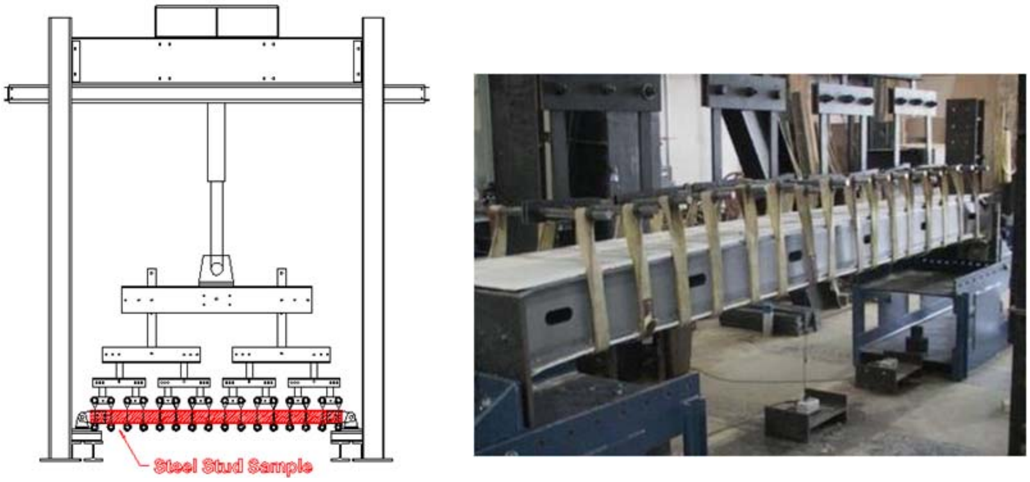


Figure 4: CCA Experimental Setup

Full-Scale Experimental Series. With knowledge acquired from the component level series of experiments, a full-scale series is planned to evaluate the effects of span length, materials, and connection design on wall system behavior. In this series, the incorporation of veneer will be studied as a point of additional capacity. Figure 5 shows the proposed setup with a 16-point loading tree and an arbitrary sample.



(a) (b)

Figure 5: Loading Tree Experimental Setup

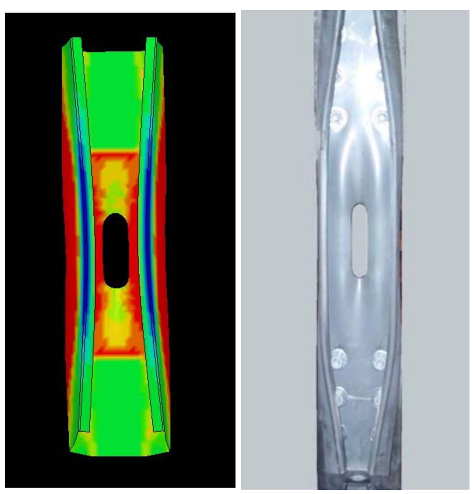


Figure 6: Comparison of FE Model and Tension Test Specimen Tested at University of Missouri

Computational Modeling. To compliment the physical testing program, computer-based simulations using detailed finite element models are a major component of the ongoing research. Such models are needed to carry out parametric studies and to extend the test data beyond the range of specimens that can be physically tested during the research program. Because of the complicated failure mechanisms observed in past blast tests on steel stud walls, it is important to understand the role played by individual components in controlling the overall behavior of a typical wall assembly. Thus, the development of detailed finite element models parallels the

physical testing program. To date, several different types of finite element models have been developed. Simple tension specimen models have been developed, and computed results show good agreement with past tests at the University of Missouri (Figure 6) (Shull, 2002).

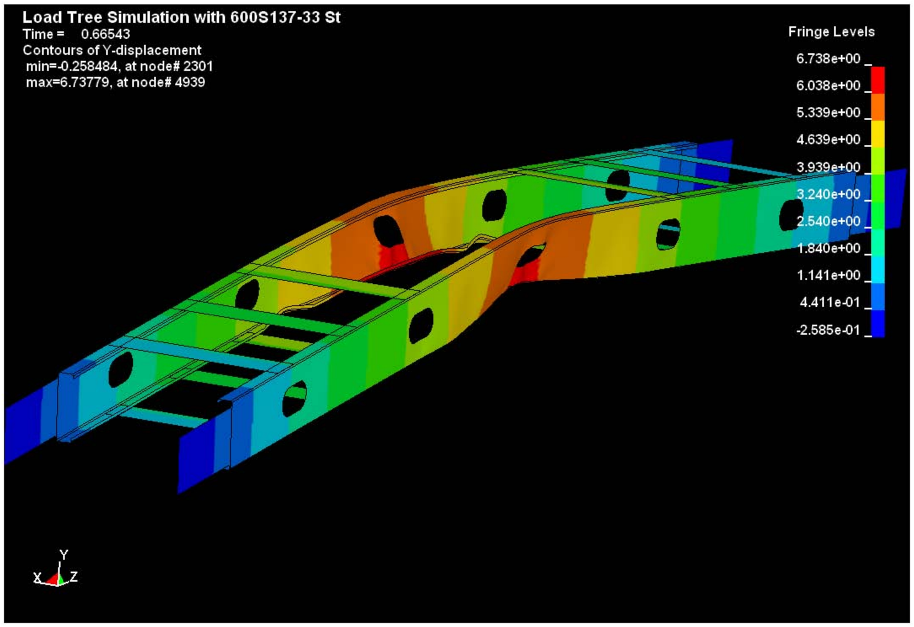


Figure 7: Simulation of Load Tree Specimen with Idealized Connections

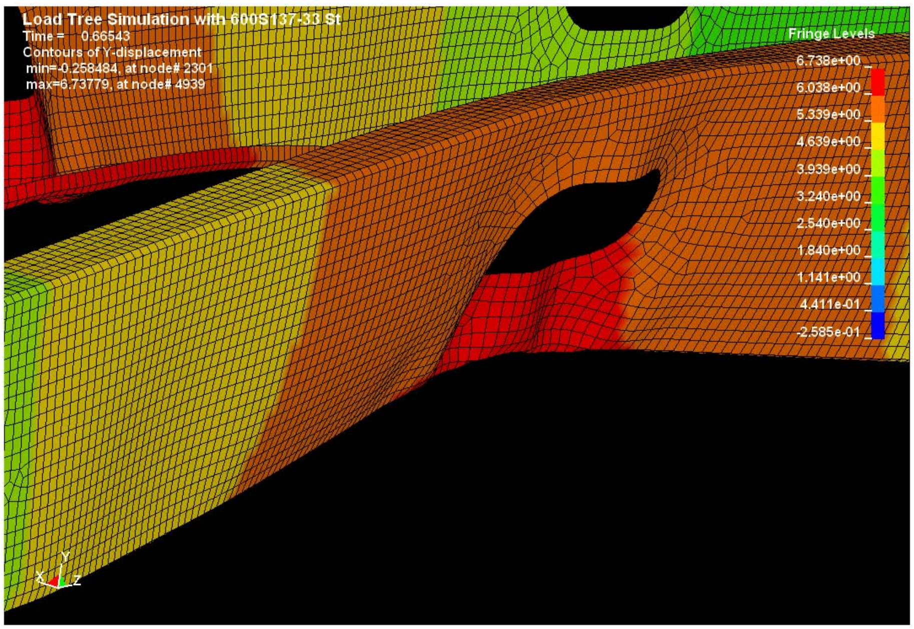


Figure 8: Simulation of Load Tree Specimens with Idealized Connections - Close-Up View of Critical Mid-Span Region

Figure 9: Finite Element Model of Specimens with Realistic Slip-Track Support Conditions

As indicated by Figures 7 and 8, simulation models to date have been able to capture the local buckling and yielding of material that occurs at the critical mid-span region of uniformly loaded studs. While the general trend in response agrees well with observations from similar tests in the past, detailed data are needed to validate the predictions of the finite element models. These data will become available once the physical testing program described above is completed. Figure 9 shows the modeling of realistic support details that are common in practice. In this particular figure, a specimen representing a non-load-bearing wall is shown; it utilizes a slip track connection.

SUMMARY AND CONCLUSIONS

Laboratory experiments isolate structural behaviors, allowing for theoretical analyses to be developed that describe localized behaviors. For conventional steel stud construction, TMA, BPA, and CCA experiments isolate behaviors building up to wall component experiments to predict the blast response for conventional designs. Knowledge gained by the TMA series will assist in setting limit states for a selection of connection designs utilizing an inexpensive addition of screws above the common single screw used in practice. The BPA series defines the rotation of a stud track connection in order to define the rotation limits and the connection behavior under bending stresses. The CCA series defines the behavior of a conventional connection design subjected to stresses that induce web crippling and helps define how much of the applied loading is absorbed through shear in the studs. Full-scale component experiments as outlined in this paper provide the knowledge to predict which of the isolated connection response mechanisms will occur within a steel stud wall design based on span, connection detail, and sheathing detail.

The methodologies produced by this work will be validated against measured blast data. Any gaps in the data set will be supplemented with computational experiments. The results of the research are expected to be improved methodologies for the design of conventional steel stud structures against typical blast threats as outlined in the UFC (UFC, 2007). This research bridges the gap between conventional fully-elastic based design and the full tensile membrane capacity blast design to provide guidance for construction details that meet the anti-terrorism UFC requirements in an economical manner.

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REFERENCES

Dinan, R. (2005). “Blast Resistant Steel Stud Wall Design.” Doctoral Dissertation, University of Missouri, Department of Civil Engineering, Columbia, MO 65211-2200.

DiPaolo, Beverly P. and Stanley C Woodson (2006). “An Overview of Research at ERDC on Steel Stud Exterior Wall Systems Subjected to Severe Blast Loading.” *ASCE Structures Congress*, May 18-20, 2006, St. Louis, MO, USA.

Grumbach, Steven D., Clay Naito, and Robert J. Dinan (2007). “Use of Precast Concrete Walls for Protection of Steel Stud Construction.” *78th Shock and Vibration Symposium*, November 4-8, 2007, Philadelphia, PA, USA.

Salim, H., R. Dinan, and P. T. Townsend (2005). “Analysis and Evaluation of In-Fill Steel-Stud Wall Systems under Blast Loading.” *J. of Structural Engineering*, ASCE, 131(8), 1216-1225.

Salim, H., P. Muller, and R. Dinan (2005). “Response of Conventional Steel Stud Wall Systems under Static and Dynamic Pressure.” *J. of Performance of Constructed Facilities*, ASCE, 19(4), 267-276.

Shull, J. (2002). “Steel Stud Retrofit Connection Development and Design.” Masters Thesis, University of Missouri, Department of Civil Engineering, Columbia, MO 65211-2200.

SBEDS (2008), Single-degree-of-freedom Blast Effects Design Spreadsheet, U.S. Army Corps of Engineers, Protective Design Center (PDC).

Unified Facilities Criteria (UFC) 04-010-01, (2007). *DoD Minimum Antiterrorism Standards for Buildings*, 22 January 2007.